Amendment No. 1
Work Plan
Monitored Natural Attenuation (MNA)
Pilot Study

Old Mill Superfund Site
Rock Creek, Ohio

November 2007

BROWN AND CALDWELL

1.0 INTRODUCTION

A Work Plan has been developed to conduct a Monitored Natural Attenuation (MNA) Pilot Study at the Old Mill Superfund Site in Rock Creek, Ohio (Brown and Caldwell, 2006). That Work Plan serves as an addendum to the existing approved Long-Term Monitoring Program (LTMP) Work Plan (Brown and Cadlwell, 2001). The MNA Pilot Study Work Plan was approved by Ohio Evironmental Protection Agency (OEPA) in their letter dated October 24, 2004. The purpose of the Pilot Study is to further evaluate whether MNA, or enhanced MNA, is a viable alternative to the existing groundwater remediation system that has been operating at the Site since 1989, and could facilitate returning the Site to productive community use in a shorter timeframe. The MNA Pilot Study has been designed to last four years.

This document serves as Amendment No. 1 to the MNA Pilot Study Work Plan. This Amendment addresses the Hydrogen Release Compound-Advanced® (HRCA) application frequency and verification sampling during the MNA Pilot Study at the Site.

2.0 MODIFICATIONS TO WORK PLAN

The MNA Pilot Study Work Plan specifies quarterly applications of HRCA into four former groundwater collection trenches and two monitoring wells at the Site. The initial application occurred in December 2006 and the second in March 2007. In accordance with discussion with OEPA in June 2007, the originally scheduled June and September 2007 applications were postponed pending review of Site conditions and input from the HRCA manufacturer, Regenesis. Consequently, the modifications to the HRCA application frequency and the supplemental verification sampling presented herein are the result of the following:

- Review of the March 2007 and June 2007 sampling results indicating no breakthrough of contaminants beyond the trenches following the groundwater collection/treatment de-activation in December 2006;
- The presence of residual HRCA in the trenches and monitoring wells, visually observed in June and September 2007;

- HRCA Technical Bulletin 1.0 prepared by Regenesis (Attachment A);
- Discussions with Regenesis; and
- Regenesis' site-specific recommendations contained in their June 19, 2007 letter (Attachment B).

The original quarterly HRCA application frequency outlined in the Work Plan included conservatism due to uncertainties associated with the longevity of the relatively new product being used, and the desire to introduce ample electron doner to the shallow aquifer during the early stages of the Pilot Study. At the time HRCA was selected as the electron doner, Regenesis' published technical information on the product was limited. The Work Plan recognized the uncertainties involved and acknowledged that modifications to the application method and frequency were possible as the MNA Pilot Study advanced.

As Regenesis indicate in their HRCA Technical Bulletin and June 19, 2007 letter, longevity of HRCA in aquifers can range from one to two years to four or more years, depending on the nature of the aquifer. Longevities are normally longer for finer-grained aquifer systems, similar to the shallow aquifer at the Old Mill Site. The extended longevity of HRCA at the Site was evidenced in June 2007 when significant residual HRCA was apparent in the four application trenches and two monitoring wells, remaining from the December 2006 and March 2007 application events.

Based on the information discussed above and evaluation of site-specific conditions, the following modifications to the Work Plan were proposed:

1. Semi-annual sampling of the four application trenches and two application monitoring wells for HRCA indicator parameters to establish the HRCA application frequency. The target indicator parameters will include metabolic acids, total organic carbon (TOC), and the bioparameters described in the Work Plan (e.g., DO, pH, ORP, temperature, conductivity, manganese-II, iron-II, sulfide, sulfate, nitrates, chloride, carbon dioxide and turbidity). This supplemental semi-annual sampling will run concurrently with the semi-annual sampling program described in the Work Plan. The next sampling event will be in December 2007. However, this supplemental sampling

may be waived for a location during a sampling event if significant residual HRCA is visually evident, indicating that adequate HRCA remains. Also, once a site-specific correlation is established between TOC and the metabolic acids, the acids will be removed from the target parameter list;

2. The HRCA application frequency will be reduced from quarterly to annually, or as indicated by the semi-annual sampling described above; and

3. The HRCA application method be modified from concentrated (i.e., “neat”) addition of HRCA to the “micro-emulsion” method, consisting of mixing the specified volume of HRCA with potable water at a targeted dilution rate of 10:1 (10 gallons of water to 1 gallon of HRCA);

3.0 REFERENCES

Brown and Caldwell, 2001. Work Plan for Long-Term Operation and Maintenance at the Old Mill Superfund Site, June 2001.

Brown and Caldwell, 2006. Work Plan for Monitored Natural Attenuation (MNA) Pilot Study at the Old Mill Superfund Site, September 2006.

ATTACHMENT A

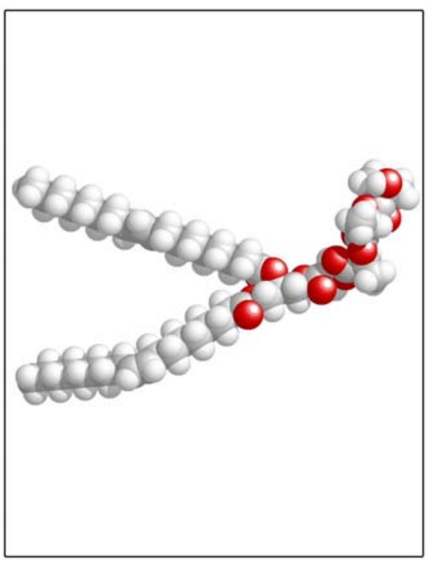
Hydrogen Release Compound Advanced

(HRC Advanced®)

Introduction

HRC Advanced® is the new paradigm in time-release electron donors for groundwater and soil remediation. HRC Advanced is based upon a new molecular structure (patent applied for) designed specifically to optimize anaerobic degradation of contaminants in subsurface environments. This structure incorporates esterified lactic acid (technology used in HRC) and esterified long chain fatty acids. The advantage of this structure is that it allows for the controlled-release of lactic acid (which is among the most efficient electron donors) and the controlled-release of fatty acids (a very cost-effective source of slow release hydrogen). Upon injection, the controlled-release of lactic acid dominates serving to initiate and stimulate anaerobic dechlorination. Over time the controlled-release of fatty acids will dominate, acting to continue microbial stimulation. The expected single-injection longevity of this product is 1-2 years and in excess of 4 years under optimal conditions, e.g. concentrated application in low permeability, low consumptive environments.

HRC Advanced is a slightly viscous liquid that incorporates a molecular structure composed of tetramers of lactic acid (polylactate) and fatty acids esterified to a carbon backbone molecule of glycerin.



The image to the left illustrates a ball-and-stick version of the glycerol ester in HRC Advanced. Oxygen atoms are shown in red, carbon atoms in grey, and hydrogen atoms in white. The long chains represent the fatty acid components of the molecule.

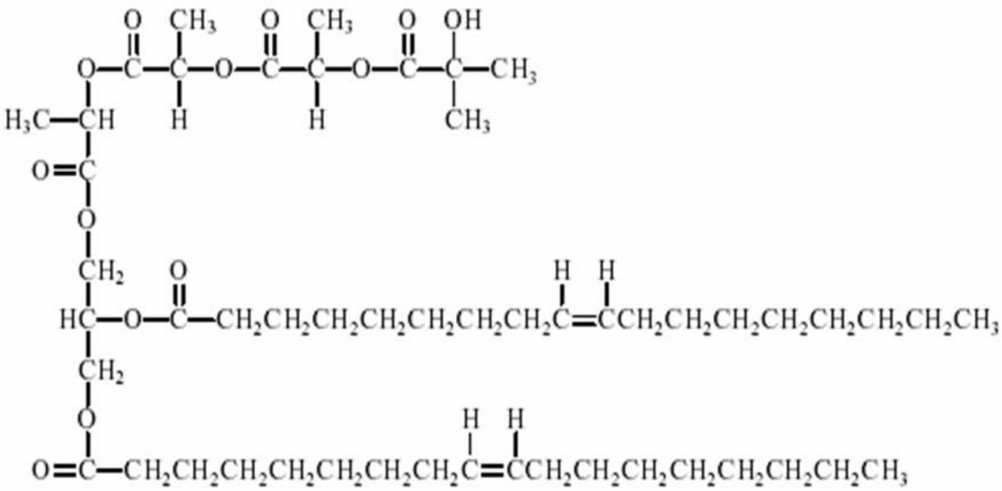
When HRC Advanced is placed in water, free lactic acid immediately begins to ferment which initiates reductive dechlorination and subsequent contaminant treatment. Over time the ester bonds begin to cleave, producing dissolved-phase lactic acid and fatty acids. HRC Advanced also contains free fatty acids for additional electron donating capacity. Thus, HRC Advanced provides the benefits of lactic acid, a rapidly fermented substrate and excellent hydrogen source, as well as fatty acids, which are slower to ferment and provide hydrogen to a contaminated site over extended time periods. This combination of lactic acid and fatty acids provides a functional longevity of 1-2 years for most sites (>4 years under optimal conditions). HRC Advanced creates an anaerobic system in a redox range where bacteria known to be responsible for reductive dechlorination flourish. Maintaining these conditions provides maximum utilization of the electron donor for reductive dechlorination, rather than simply providing excess carbon per unit time which can result in excess methane production, as simple soluble substrates often do.

HRC Advanced Attributes:

- Incorporates proven Hydrogen Release Compound (HRC®) base materials
- Provides a persistent and significant source of hydrogen
- Typical single-injection longevity of 1-2 years and over 4 years under optimal conditions
- Achieve wide subsurface distribution when applied as microemulsion
- Easily applied with readily available direct injection equipment

Molecular Diagram

The following chemical structure shows the glycerol ester (patent applied for). The top “prong” is the tetramer of polylactate (look for 4 double bonded O atoms). The middle and bottom “prongs” are fatty acids.



ATTACHMENT B

June 19, 2007

Mike Watkins
Brown and Caldwell
7550 Lucerne Drive
Middleburg Hts, OH 44130
E-mail: mwatkins@brwncald.com

Subject: Application of HRC *Advanced* (Advanced Formula Hydrogen Release Compound) at the Northeast Ohio Superfund Site Site

Dear Mr. Watkins:

Pursuant to your request we have reviewed your plan for application of our Advanced formula Hydrogen Release Compound (HRC *Advanced*™) product at the Superfund Site located in Northeast Ohio.

Our understanding is that you have added 1,500 pounds of HRC Advanced in concentrate form during two separate events in December 2006 and March 2007. Using conservative default competing electron acceptor and groundwater velocity values to determine "worst-case" flux through the trenches, we have estimated that approximately 1,320 pounds of HRC Advanced concentrate is sufficient to meet the demand for electron donor material persistence within the trenches. This quantity also correlates to an approximate 10% pore space occupancy of the saturated portion of the trenches which is a typical target goal for these types of applications. Therefore, the amount of HRC Advanced that has been placed in the trenches thus far should be sufficient for this barrier-trench application.

The longevity of HRC Advanced is approximately 2 to 3 years or longer in some cases. It's longevity is determined by a variety of factors related to the utilization of hydrogen as an alternate electron acceptor for reductive dechlorination. Some of the more prominent factors include competing electron acceptor (i.e, sulfate, nitrate, DO, etc.) demand, groundwater velocity and contaminant concentrations. Testing of the longevity or, persistence of HRC Advanced should be conducted to determine when future applications are necessary. Since HRC Advanced has been applied in concentrate form twice, it may be possible to collect a water sample from the trenches and observe whether or not neat material is still present. If net material is not observed, we recommend that samples be collected on a quarterly basis for metabolic acids. These typically include: pyruvic, proprionic, lactic, butyric and acetic acids. We also recommend that a sample be collected for total organic carbon (TOC). After a few sampling events you may be able to establish a correlation between TOC and metabolic acids and when this correlation is established, it may be sufficient to discontinue sampling for the acids and begin testing for TOC only. As long as TOC is present in sufficient amounts in the trenches (10^2 part per million range), and its presence can be correlated to HRC Advanced breakdown to metabolic acids, there is no need for an additional application. In addition to TOC and metabolic acids, we also recommend sampling for standard geochemical parameters including: dissolved oxygen, oxidation-reduction potential, total and dissolved iron, sulfate, nitrate and methane data should be collected from within the trenches and compared to a background location outside of the contaminated area. I've attached a typical HRC Advanced application groundwater monitoring protocol for your consideration. Please note that we do not recommend HRC Advanced be applied in June 2007 as originally scoped.

We recommend future applications be conducted using a 10:1 (10 parts water to 1 part HRC Advanced concentrate) micro-emulsion. The reason for this recommendation is that it will allow for greater pore space distribution and will result in a more efficient application of the product, including more efficient lactate release, while maintaining electron donor persistence within the trenches (and in the soil pores surrounding the trenches). We recommend a ratio of 1,320 pounds of HRC Advanced mixed with 1,600 gallons of water to create the microemulsion. This material should be distributed evenly, to the extent possible, within the trenches. Supporting calculations and the standard microemulsion mixing instructions are attached.

We appreciate the opportunity to work with you on this project. If you have any questions, feel free to contact me.

Sincerely,
Regenesis

Douglas Davis
Technical Services Manager – Central Region

Attachments: 1) HRC Advanced Groundwater Monitoring Program
2) Supporting HRC Advanced Calculations
3) HRC Advanced Mixing Instructions

REGENESIS

Recommended Groundwater Monitoring Program for an HRC *Advanced*™ Project

In order to validate the effectiveness of natural attenuation processes (via HRC *Advanced*-enhanced treatment), we recommend conducting groundwater monitoring at selected wells. A baseline round of sampling should be performed to identify the groundwater quality/conditions prior to the injection of HRC *Advanced*. After the product has been installed, we recommend monthly monitoring of the following field parameters: DO, ORP, temperature, pH, dissolved and total Fe and Mn. Monitoring of laboratory analyses for metabolic acids and dissolved gases should be conducted monthly or quarterly. Additional sampling can be performed every other month for a six- to twelve-month period. After the initial biodegradation and geochemical trends have been identified, the monitoring frequency can be decreased to a quarterly, semi-annually, or annually. In addition, if a correlation between the concentrations of metabolic acids and the concentration of TOC in groundwater can be established, the TOC may be used as a substitute for the acid analyses.

The following tables outline the parameters and methods that should be used to monitor the progress of an HRC *Advanced* -based project.

Groundwater Monitoring Parameters – Lab Only	
Analyte	**Method**
Chlorinated Volatile Organic Compounds (VOCs)	**EPA 8260**
Total organic carbon (TOC)[1]	**EPA 415.1 or EPA 9060**
Metabolic acids[2]**: lactic, pyruvic, acetic, propionic, and butyric (generated from HRC *Advanced* release)**	**HPLC/UV** **(Call labs to determine appropriate methodology)**
Nitrate	**EPA 353.1 or EPA 9056**
Sulfate	**EPA 375.3 or EPA 9056**
Carbon Dioxide, Methane, Ethane, Ethene (all optional)	**ASTM D1945**

[1] TOC on soil for design phase

[2] Regenesis recommends a detection limit of 1.0 mg/L for acetic, butyric, lactic and propionic acids. If possible, a detection limit of 0.1 mg/L should be used for pyruvic acid.

** A specially qualified laboratory should do the analytical testing for the metabolic acids; otherwise most laboratories can provide testing for the remaining parameters.

Groundwater Monitoring Parameters – Field or Lab	
Analyte	**Method**
pH, dissolved oxygen (DO), oxidation/reduction potential (ORP), temperature	**Meter reading taken in flow-through cell (DO can also be measured with a Hach field test kit.)**
Total and dissolved iron and manganese	**Colorimetric Hach Method or EPA 6000 series with filtered and unfiltered samples**
Sulfide	**Colorimetric Hach Method or EPA 376.2**

Groundwater Monitoring Locations

The following table outlines the suggested locations and significance of monitoring wells used to monitor the progress of an HRC *Advanced* -based project.

Location	Significance
Background (Outside the groundwater plume)	Allows for the changes in natural attenuation conditions induced by addition of HRC *Advanced* to be compared to background levels
Upgradient of treatment zone	Provides a measure of contaminant and competing electron acceptor flux entering treatment zone
Inside treatment zone	Provides information on how HRC *Advanced* is affecting the aquifer conditions and contaminant concentrations
Downgradient of treatment zone	Provides information on the effect HRC *Advanced* is having on the biodegradation rates of contaminants and on aquifer conditions

Brown & Caldwell Mike Watkins - NE Ohio Superfund Site - Barrier HRC-A Calculations

Trench Length	750	ft
Saturated Thickness	3	ft
Trench Width	3	ft
Saturated Trench Volume	6750	ft3
Porosity	0.35	
Pore Volume	2362.5	ft3
Gallons/ft3 (conversion)	7.48	
Pore Volume	17671.5	Gallons
10% Occupancy w/ 10:1 HRC-A Microemulsion	1767.15	Gallons
Breakout:		
Gallons HRC-A Concentrate	160.65	
Gallons Water	1606.5	
3.7 Gallons/30-lb Bucket HRC-A Concentrate	43.418919	Buckets
Roundup to next bucket	44	Buckets
HRC-A Concentrate per Application	1320	Pounds
Mix Ratio	***1320***	***lbs HRC-A***
	1607	***Gallons Water****

***Note - Amount of Water can be increased to as much of pore space as desired**

Hydrogen Release Compound Advanced
(HRC Advanced™)

INSTALLATION INSTRUCTIONS

High-Volume, Wide-Area, Micro-Emulsion Application

Introduction

HRC Advanced™ (HRC-A) should ONLY be applied as a high-volume, micro-emulsion. In this form it offers greater physical distribution of the HRC-A material across a larger potential radius from a single injection point. The production of an HRC-A emulsion involves the on-site, volumetric mixing of 10 parts water with 1 part delivered HRC-A concentrate to form the injection-ready HRC-A micro-emulsion. This micro-emulsion suspension can then be injected directly or further diluted to a predetermined ratio of HRC-A to water. The following instructions provide details in the production and installation of the HRC-A micro-emulsion.

Material Overview Handling and Safety

HRC-A concentrate is shipped and delivered in 4.25-gallon buckets. Each bucket has a gross weight of approximately 32 pounds. Each bucket contains 30 pounds of HRC-A concentrate (net weight) and a nominal volume of 3.7 gallons. At room temperature, HRC-A concentrate is a liquid material with a viscosity of approximately 500 centipoise, roughly the equivalent of pancake syrup. The viscosity of HRC-A is not temperature sensitive above 50 ºF (10 ºC). However, below 50 ºF the viscosity may increase significantly. If the user plans to apply the product in cold weather, consideration should be given to heating the material to above 60 ºF so that it can be easily handled. HRC-A concentrate should be stored in a warm, dry place that is protected from direct sunlight. It is common for stored HRC-A concentrate to settle somewhat in the bucket, a quick pre-mix stir by a hand held drill with a paint or "jiffy mixer" attachment will rapidly re-homogenize the material. HRC-A concentrate is non-toxic, however field personnel should take precautions while handling and applying the material. Field personnel should use appropriate personal protection equipment (PPE) including eye protection. Gloves should be used as appropriate based on the exposure duration and field conditions. A Material Safety Data Sheet is provided with each shipment. Personnel who operate field equipment during the installation process should have appropriate training, supervision, and experience and should review the MSDS prior to site operations.

Micro-Emulsion Production HRC-A to Water Ratio

HRC-A concentrate should be mixed with water on a volume to volume (v/v) basis to produce a micro-emulsion starting at 10 parts water: 1 part HRC-A. Although micro-emulsions can be easily produced using greater water volumes than 10 parts, e.g. 20 to 50 parts water to 1 part HRC-A, the initial micro-emulsion should never be produced below a ratio of less than 10 parts water: 1 part HRC-A v/v. **WARNING: Do not attempt to produce a micro-emulsion at less than 10 parts water to 1 part HRC-A ratio v/v. This will produce an undesirable and unstable solution.**

The field production of HRC-A micro-emulsion is a very simple procedure; however, it is critical that the user follow the mixing directions outlined below. Never attempt to add water to the HRC-A as this will produce an undesirable and unstable large emulsion. Always add the HRC-A to a large volume of water.

As indicated previously the 10:1 ratio of water to HRC-A v/v is the minimum water ratio that can be used, a greater ratio (more dilute solution) can easily be achieved and is governed by: A) the volume of HRC-A required to treat the estimated contaminant mass, B) the pore volume in which the material is applied, C) the time available for installation (gallons/pump rate), and C) the estimated volume of HRC-A micro-emulsion that the target zone will accept over the time period allocated for installation.

Conceptually, although a higher volume of water to volume of HRC-A will produce a larger volume of the suspension, it will lower the concentration of HRC-A per gallon of solution. Thus, the benefit of using a high water/HRC-A v/v ratio in order to affect a greater pore volume of the subsurface aquifer is offset by the dilution of the HRC-A per unit volume of suspension as well as by the limitations of the subsurface hydraulic conductivity and effective porosity (capacity of the aquifer to accept the volume of HRC-A micro-emulsion).

It is important that the user plan in advance the v/v HRC-A/water ratio to be employed at a project site. The resulting volume of solution will dictate the site water requirements and the time required for injection, etc. If upon injection of greater than 10:1 HRC-A micro-emulsion, the subsurface does not readily accept the volume of solution as designed, the user can adjust downward the v/v water to HRC-A ratio until a more concentrated suspension is produced (this solution should never drop below the required 10 parts water:1 part HRC-A v/v production ratio). For more information on designing a HRC-A/water ratios to meet specific site conditions, please contact Regenesis Technical Services.

Direct Push Application Requirements

One of the best methods to deliver the HRC-A micro-emulsion into the subsurface is to pressure inject the solution through direct-push rods using hydraulic equipment, or to pressure inject/gravity feed the micro-emulsion into the dedicated injection wells. The use of low cost push points or temporary injection points allows the applier to more cost effectively distribute the HRC-A material across shallow sites by employing multiple points per site. In the case of treating deep aquifer sites, the use of the micro-emulsion applied via dedicated injection wells is likely to be the most cost effective remediation approach. Please note that this set of instructions is specific to direct-push equipment. Please contact Regenesis Technical Services to assist you with dedicated injection well applications.

In general, Regenesis strongly recommends application of the HRC-A micro-emulsion using an injection pump with a minimum delivery rate of three gallons per minute (gpm) and a pressure rating of between 150 to 200 pounds per square inch (psi). **Note: the <u>injection pump requirements are different than the requirements of the mixing pump</u> (see Mixing to Generate HRC-A Micro-emulsion).** High pressure, positive displacement pumps and progressive cavity pumps are appropriate for injecting HRC-A. For low permeability lithologies (clay, silt) higher pressure pumps (800-1600 psi) may be necessary, while for more permeable lithologies (gravel, sand) a lower pressure pump may be adequate. Examples of appropriate pumps are: Rupe Models 6-2200, 9-1500 and 9-1600 (positive displacement), Geoprobe® GS-2000 (positive displacement) and DP-800 (progressive cavity), Yamada (air diaphragm), Moyno (progressive cavity), and Wilden (air diaphragm). Delivery rate is a critical factor in managing installation time and costs. Generally, higher delivery rates (>6 gpm) are more cost effective for these types of applications but pump selection should be on a site specific basis and account for the volume of HRC-A solution and specific aquifer conditions present at the site.

The installation of the HRC-A micro-emulsion should span the entire vertical contaminated saturated thickness. If the vertical extent of the application is confined to a limited interval, then the micro-emulsion should be placed across a vertical zone extending a minimum of one-foot above and one-foot below the screened interval of monitoring wells that are being used to evaluate the performance of the project.

Producing the HRC-A Micro-Emulsion

The application of HRC-A requires the creation of a micro-emulsion. Technically the optimal suspension is an HRC-A-in-water suspension containing micro-emulsions. Before beginning the mixing procedure the user should have in mind the desired water to HRC-A ratio v/v desired.

It is critical that the micro-emulsion be produced using a high-shear apparatus such as a high speed centrifugal pump. The shearing provided by the vanes in these types of pumps is sufficient to form and maintain a homogeneous milky emulsion. **<u>This pump will be a different pump than that used to inject the HRC-A micro-emulsion into the subsurface</u>.** If the user is uncertain as to requirements for the pump or the applicability of a certain pump, please contact Regenesis Technical Services. Regenesis typically suggests using a water trailer/pump apparatus commonly found at equipment rental facilities. Regenesis recommends using a Magnum Products LLC model MWT500 or equivalent water trailer (fitted with centrifugal recirculation pump). This "trash pump" or transfer pump is an ideal high shear pump and the water tank (400 gallons) serves as an excellent mixing tank.

<u>To ensure that proper micro-emulsion suspension is generated Regenesis suggests a two-step process that simply requires mixing at least 10 parts water to 1 part HRC-A concentrate using water at a temperature ≥ 60°F.</u>

Step 1) Regenesis recommends that the HRC-A concentrate in each bucket be re-homogenized using a drill equipped with a paint or "jiffy" mixer attachment as minor settling may have occurred during shipment.

Step 2) to calculate the volume of water necessary to produce a 10:1 v/v micro-emulsion, each bucket of HRC-A concentrate containing 3.7 gallons of material should be mixed with 37 gallons of water.

Example: 6 buckets x 3.7 gallons HRC-A concentrate/bucket yields a total of 22.2 gallons of HRC-A concentrate. Thus, a 10:1 v/v solution will require 222 gallons of water (22.2 gallons HRC-A concentrate x 10 gallons water yields 222 gallons of water). A nominal total volume micro-emulsion would result from the summation of the HRC-A concentrate volume (22.2 gallons) and the water volume (222 gallons). This yields a total fluids delivery volume of approximately 244 gallons.

The previously calculated water volume (222 gallons) should be transferred into an appropriately sized mixing tank. The water should be circulated by the high shear centrifugal pump and each of the six HRC-A buckets slowly poured into the tank. Each bucket of HRC-A concentrate should be poured at a slow rate (approx. 1 minute per bucket) and the contents of the tank continually recirculated using the high hear centrifugal pump. A period of 1-2 minutes should be allowed between addition of each subsequent bucket of HRC-A concentrate to allow the centrifugal pump to continue to shear and mix the water/HRC-A concentrate. Upon addition of the entire volume of HRC-A concentrate the pump should remain on to allow the solution mixture to recirulate. The recirculation of the HRC-A micro-emulsion should continue until the material is injected to maintain micro-emulsion consistency.

Application of Micro-Emulsion Using Direct-Push Methods

1) Prior to the installation of the micro-emulsion, any surface or overhead impediments should be identified as well as the location of all underground structures. Underground structures include but are not limited to: utility lines, tanks, distribution piping, sewers, drains, and landscape irrigation systems.

2) The planned installation locations should be adjusted to account for all impediments and obstacles.

3) Pre-mark the installation locations, noting any points that may have different vertical application requirements or total depth.

4) Set up the direct-push unit over each specific point and follow the manufacturer's standard operating procedures (SOP). Care should be taken to assure that probe holes remain vertical.

5) For most applications, Regenesis suggests using drive rods with an O.D. of at least 1.25-inches and an I.D. of at least 0.625-inches I.D (Geoprobe or equivalent). However, the lithologic conditions at some sites may warrant the use of larger 2.125-inch O.D./1.5-inch I.D. drive rods.

6) The most typical type of sub-assembly currently being used is designed for 1.25-inch direct-push rods and is manufactured by Geoprobe. Other brands of drive rods can also be used but require the fabrication of a sub-assembly that allows for a connection between the pump and drive rod.

7) For mixing large volumes of the micro-emulsion, Regenesis recommends using a Magnum Products LLC model MWT500 water trailer (fitted with centrifugal recirculation pump) or equivalent unit. However, single large volume poly tanks are adequate. We suggest filling the tank with an appropriate quantity (e.g. from the example above 222 gallons) of water before start of mixing operations. The tank should be configured so that both a hose and a fire hydrant or larger water tank can be connected to it simultaneously and filled with water quickly and easily. This will dramatically reduce the time needed to fill the tank with mixing water.

8) Regenesis highly recommends preparing the micro-emulsion before pushing any drive rods into the subsurface. NOTE: it is best if the micro-emulsion is produced a single day application volumes.

9) After the micro-emulsion mixing/shearing step has been completed as described above, the micro-emulsion is ready to be applied. Check to see if a hose has already been attached to the inlet side of the centrifugal pump. If this has not been done, do so now.

10) If a non-water trailer tank is being used for mixing the micro-emulsion a stand alone centrifugal pump and hose system should be used for the shearing and mixing operations.

11) Advance drive rods through the ground surface, as necessary, following SOP.

12) Push the drive rod assembly with an expendable tip to the desired maximum depth. Regenesis suggests pre-counting the number of drive rods needed to reach depth prior to starting injection activities to avoid any miscalculations.

13) After the drive rods have been pushed to the desired depth, the rod assembly should be withdrawn three to six inches. The expendable tip can be dropped from the drive rods, following SOP.

14) If an injection tool is used instead of a direct-push rod with an expendable tip, the application of material can take place without any preliminary withdrawal of the rods.

15) In some cases, introduction of a large column of air may be problematic. This is particularly the case in deep injections (>50 ft) with large diameter rods (>1.5-inch O.D.). To prevent the injection of air into the aquifer during the application, fill the drive rods with HRC-A emulsion after they have been pushed to the desired depth and before the disposable tip has been dropped or before the injection tip is operational.

16) Transfer the appropriate quantity of the micro-emulsion from the water trailer to the working/application pump hopper or associated holding tank.

17) A volume check should be performed prior to the injection of the micro-emulsion. Determining the volume discharged per unit time/stroke using a graduated bucket and stopwatch or stroke counter.

18) Start the pump and use the graduated bucket to determine how many gallons of micro-emulsion are delivered each minute or stroke per unit volume.

19) Connect the 1.25-inch O.D., 1-inch I.D. delivery hose to the pump outlet and the appropriate sub-assembly. Circulate the micro-emulsion through the hose and the sub-assembly to displace any air present in the system.

20) Connect the sub-assembly to the drive rod. After confirming that all of the connections are secure, pump the micro-emulsion through the delivery system to displace any water or other fluids in the rods.

21) The pump engine RPM and hydraulic settings should remain constant throughout the day to maintain a constant discharge rate.

22) The material is now ready to be installed in the subsurface. Use the pumps discharge rate as calculated in step 18 to determine the withdrawal rate of the drive rods needed for the application.

23) Slowly withdraw the drive rods using Geoprobe Rod Grip or Pull Plate Assembly (Part AT1222-For 1.25-inch drive rods). While slowly withdrawing single lengths of drive rod (three or four feet), pump the pre-determined volume of micro-emulsion into the aquifer across the desired treatment interval.

24) Remove one or two sections of the drive rod at a time. The drive rod may contain some residual material so Regenesis suggests placing it in a clean, empty bucket and allowing the material to drain. Eventually, the material recovered in the bucket should be returned to the pump hopper for reuse.

25) Observe any indications of aquifer refusal such as "surfacing" around the injection rods or previously installed injection points. If aquifer acceptance appears to be low, allow enough time for the aquifer to equilibrate prior to removing the drive rod.

26) Repeat steps 19 through 25 until treatment of the entire contaminated vertical zone has been achieved.

27) Install an appropriate seal, such as bentonite, above the micro-emulsion injection zone. The seal should span across the entire vadose zone. Depending on soil conditions and local regulations, a bentonite seal using chips or pellets can be used. If the injection hole remains open more than three or four feet below the ground surface sand can be used to fill the hole and provide a base for the bentonite seal. The installation of an appropriate seal assures that

the micro-emulsion remains properly placed and prevents contaminant migration from the surface. If the micro-emulsion continues to "surface" up the direct-push borehole, an oversized disposable drive tip or wood plug/stake can be used to temporarily plug the hole until the aquifer equilibrates and the material stops surfacing.

28) Remove and clean the drive rods as necessary.

29) Finish the borehole at the surface as appropriate (concrete or asphalt cap, if necessary).

30) Periodically compare the pre- and post-injection discharge rates of the micro-emulsion in the pump hopper or holding tank using any pre-marked volume levels. If volume level indicators are not on the pumps hopper or holding tank use a pre-marked dipstick or alternatively temporary mark the hopper or holding tank with known quantities/volumes of water using a carpenter's grease pencil (Kiel crayon).

31) Move to the next probe point, repeating steps 11 through 29.

Helpful Hints

1) *Application in Cold Weather Settings*

As discussed in the Material Overview, Handling, and Safety section, cold weather tends to increase the viscosity of HRC-A as well as decrease the ease of micro-emulsion formation. To optimize an application in cold weather settings Regenesis recommends maintaining the HRC-A concentrate and the associated water at a temperature ≥60ºF (16ºC). The following procedures can be used to facilitate the production and installation of a 10:1 v/v HRC-A micro-emulsion.

- Raise and maintain the temperature of the HRC-A to at least 60°F (16°C) prior to mixing with water. A hot water bath can be used to heat up the HRC-A concentrate buckets. A Rubbermaid fiberglass Farm Trough Stock Tank (Model 4242-00-GRAY) has been used for this process. This trough can hold up to 16 buckets of HRC-A concentrate.
- Hot water (approximately 130-170°F or 54-77°C) should be added to the tank after the buckets of HRC-A have been placed inside. The hot water should be delivered from a heated pressure washer (Hotsy® Model No. 444 or equivalent) or steam cleaner unit.
- It is equally critical that a moderate water temperature (>60°F or 16ºC) be used in the production of the micro-emulsion. If on-site water supply is below 60ºF use a hot water or steam cleaner to generate a small volume (e.g. 5-10% of total water volume) of hot water (130–170ºF/54-77ºC). This small volume of hot water should be added to remaining cold water volume to raise the total volume temperature to >60ºF. When the HRC-A concentrate and water each reach a minimum temperature of 60°F or 16°C the two materials are ready for mixing.
- Upon achieving a minimum temperature of 60°F or 16°C (approximately 10-20 minutes). When the HRC-A and the associated water volumes have reached a minimum temperature of 60°F or 16°C (approximately 10-20 minutes) they are ready for mixing.
- In exceptionally harsh winter temperature settings use of a separate insulated pump containment structure and insulated delivery hoses may be necessary.

- Use a pump with a heater unit.
- Periodically check the temperature of the material in the hopper.
- Re-circulate the HRC-A micro-emulsion through the pump and hose to maintain temperature adequate temperatures.
- Care should be taken to avoid the re-circulation of material volumes that exceed the volume of the pump hopper or holding tank.

Table 1: Equipment Volume and HRC-A Micro-Emulsion Weight per Unit Length of Hose (Feet)

Equipment	Volume	Product Weight
1-inch OD; 0.625-inch ID hose (10 feet)	0.2 gallon	1.6 lbs.
1.25-inch OD; 0.625-inch ID drive rod (3 feet):	0.05 gallon	0.4 lbs.
1.25-inch OD; 0.625-inch ID drive rod (4 feet):	0.06 gallon	0.5 lbs.

2) Pump Cleaning

For best results, use a heated pressure washer to clean equipment and rods periodically throughout the day. Internal pump mechanisms and hoses can be easily cleaned by re-circulating a solution of hot water and a biodegradable cleaner such as Simple Green through the pump and delivery hose. Further cleaning and decontamination (if necessary due to subsurface conditions) should be performed according to the equipment supplier's standard procedures and local regulatory requirements.

NOTE:

Before using the Rupe Pump, check the following:

- Fuel level prior to engaging in pumping activities (it would be best to start with a full tank)
- Remote control/pump stroke counter LCD display [if no display is present, the electronic counter will need to be replaced (Grainger Stock No. 2A540)]

Monitor pump strokes by observing the proximity switches (these are located on the top of the piston).

3) *Bedrock Applications*

When contaminants are present in competent bedrock aquifers, the use of direct-push technology as a delivery method is not possible. *Regenesis is in the process of developing methods for applying HRC-A via boreholes drilled using conventional rotary techniques.* To develop the best installation strategy for a particular bedrock site, it is critical that our customers call the Technical Services department at Regenesis early in the design process.

The micro-emulsion can be applied into a bedrock aquifer in cased and uncased boreholes. The micro-emulsion can be delivered by simply filling the borehole without pressure or by using a single or straddle packer system to inject the material under pressure. Selection of the appropriate delivery method is predicated on site-specific conditions. The following issues should be considered in developing a delivery strategy:

- Is the aquifer's hydraulic conductivity controlled by fractures?
- Backfilling may be the better delivery method in massive, unfractured bedrock. This is particularly true in an aquifer setting with high permeability and little fracturing (such as that found in massive sandstone).
- Down-hole packer systems may be more advantageous in fractured bedrock aquifers.
    - In this case the fracture type, trends, and interconnections should be evaluated and identified.
- Are the injection wells and monitoring wells connected by the same fractures?
- Determine if it is likely that the injection zone is connected to the proposed monitoring points.
- If pressure injection via straddle packers is desired, consideration should be given to the well construction. Specific issues to be considered are:
    - Diameter of the uncased borehole (*will casing diameter allow a packer system to be used under high pressures*?).
    - Diameter of the casing (*same as above*).
    - Strength of the casing (*can it withstand the delivery pressures?*).
    - Length of screened interval (*screened intervals greater than 10 feet will require a straddle packer system*).

For further assistance or questions please contact Regenesis Technical Services at 949-366-8000.

HRC ADVANCED™ HYDROGEN RELEASE COMPOUND

Micro-emulsion